Open Spatial Data to Reporting on Accessibility of Urban Green Spaces

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Key words: urban green spaces, inclusive spaces, open data, sustainable development goal

SUMMARY

This paper presents some initial work and findings related to the application of Copernicus Sentinel-2 imagery for the calculation of the UN Sustainable Development Goals (SDG). Specifically, the SDG 11.7 related to the access of citizens living in cities to Urban Green Spaces (UGS) is under consideration. Two urban areas in Poland are the focus of the investigation: the capital Warsaw and a town called Siedlce. The experiment is based on the Copernicus Land Urban Atlas product and compared to the reference provided by the Polish National Mapping Agency. The results indicate that both cities provide their inhabitants with good access to UGS however, there is a discrepancy of approximately 10% depending on the input information applied. The main conclusion stemming from this work demonstrates that Copernicus Sentinel-2 based map products for urban areas can provide the necessary land cover class information to compute indices related to access to Urban Green Spaces.

STRESZCZENIE

W niniejszym artykule przedstawiono wstępne badania i wnioski związane z zastosowaniem zobrazowań Sentinel-2 do oceny realizacji Celów Zrównoważonego Rozwoju ONZ (SDG). W szczególności rozważany jest cel 11.7 związany z dostępem mieszkańców miast do zielonych przestrzeni miejskich (UGS). Przedmiotem badań są dwa obszary miejskie w Polsce: Warszawa i Siedlce. Eksperyment przeprowadzono w oparciu o produkt Copernicus Land Urban Atlas i porównano go z danymi referencyjnymi Głównego Urzędu Geodezji i Kartografii. Wyniki wskazują, że oba miasta zapewniają swoim mieszkańcom dobry dostęp do UGS, jednak w zależności od zastosowanych informacji wejściowych występują rozbieżności rzędu 10%. Te wstępne badania wskazują, że produkty mapowe dla obszarów miejskich oparte na programie Copernicus Sentinel-2 mogą dostarczyć niezbędnych informacji o klasie pokrycia terenu do obliczenia wskaźników związanych z dostępem do zielonych przestrzeni miejskich.

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1. INTRODUCTION

The United Nations (UN) Sustainable Develop Goal (SDG) 11 includes the target 11.7 – to provide universal access to safe, inclusive and accessible, green and public spaces, particularly for women and children, older persons and persons with disabilities. In order to provide globally consistent reporting across all nations, the SDG reporting should be based on common datasets that are accessible to stakeholders and decision makers and comparable. To provide comparable evidence of reporting on this target and demonstrate that regions and countries are working towards reaching this goal by 2030, the input data must be of high quality and available to all stakeholders including citizens for transparency. One of the first steps to reaching such a target is an understanding of the location of the green and public spaces within urban areas and linking them to both geospatial information as well as other relevant statistics which can be used to improve safety and inclusivity.

Not all urban regions have access to high quality and up-to-date geospatial information that can help them identify green public spaces. One valuable tool for such reporting is remote sensing because it can provide regular and consistent measures of the Earth's surface. The Copernicus Sentinels program was initiated for such purposes and provides a wealth of Earth Observations (EO) that are freely available and acquiring regular imagery around the globe. Specifically, the Sentinel-2 optical platform can be used for the creation of fine spatial resolution maps detailing green urban areas. In our study, we will compare different open datasets in order to understand whether they are applicable to the reporting of SDG 11.7 and produced for stakeholders who may not have access to high quality geospatial information. Our goal is to understand whether urban green products derived from EO imagery can be successfully applied to monitoring urban natural areas and potentially provide a viable substitute to larger map scale information measured by city planning offices to adequately report on the SDG 11.7. The presented methodology compares both EO and local administrative geospatial products. The EO based geospatial information is one of the Copernicus Land products: Urban Atlas which is available across Europe for communities with population greater than 100 000. We present our findings for two urban centres in Poland to compare and contrast the open EO based geospatial information with those of the local administrations. The result of testing the methods to cities in Poland, the patterns and trends observed will improve the basis for best practices of reporting this particular SDG (O'Connor et al. 2020). For example, the dependence of access to inclusive green areas on the distance from different city landmarks or transit points. Our work highlights the following important characteristics: (i) low-cost and easy to implementation because of the support of publicly available data and common algorithms for spatial analysis; (ii) universally accessible because it can be used both for reporting and monitoring of progress, and as an indicator of significant problem areas, i.e. those with the lowest access to inclusive green areas; (iii) educational because it supports the idea of open data and open science.

2. MATERIALS AND METHODS

This section describes the data that was used in the presented investigation as well as the methodologies applied. All the data used in the context of this work is open source and a valuable example of the needs associated with computing indicators that are both applicable anywhere in the world and easily compared.

2.1 DATA

For this investigation, two test areas were chosen and are both situated in the central-eastern part of Poland. The chosen urban areas are the town of Siedlce and the capital city Warsaw. Siedlce can be considered as an average size town in Poland in terms of both the demographics and economic development. Warsaw is the largest city in Poland and very urbanized with the highest population. Table 1 provides some summary information on the two chosen urban centres.

Table 1 - Summary statistics comparing the two chosen urban areas in Poland.

Test area	Type	Total population	Population density [people per km²]	Total area [km²]
Siedlce	urban (town)	76,603	2,404	31.8
Warsaw	urban (city)	1,794,166	3,469	517.24

The Copernicus Urban Atlas Product

The Urban Atlas (UA) Land Use / Land Cover classification is derived from CORINE Land Cover (Mapping guide, 2018) and is composed of 27 classes distributed across five thematic groups: ID1 = Artificial Surfaces, ID2 = Agricultural Areas, ID3 = Natural and (Semi) Natural Areas, ID4 = Wetlands, and ID5 = Water. Considering the first thematic group Artificial Surfaces (ID1), the group of land-covers that make up this thematic class include four hierarchical levels that describe the nomenclature for artificial (human made) surfaces. For example, in the first thematic group the following sub-groups are identified: urban fabric (ID 1.1), industrial, commercial, public, military, private and transport units (ID 1.2), mine, dump and construction sites (ID 1.3), and artificial non-agricultural vegetated areas (ID 1.4). These do not ideally classify the wanted land cover classes needed to directly apply for the computation of the SDG 11.7 reporting.

Another important characteristic of the UA map product is that it was produced based on a Minimum Mapping Unit (MMU) of 0.25 ha in urban areas (level 1) and a 1 ha MMU in rural areas (levels 2-5). The UA map product was based on Sentinel-2 imagery and therefore a Minimum Mapping Width was defined to be 10 m to distinguish linear features.

The Polish Database of Topographic Objects (BDOT10k)

The most accurate geospatial information that was available for these two urban centres was acquired from the official government services of Poland. This data was applied as the reference data for our work and was accessed through the Polish Database of Topographic Objects (BDOT10k) (Rozporzadzenie, 2011b). This is the official Polish National Mapping Agency dataset which is maintained by the Head Office of Geodesy and Cartography in Poland and is the reference for Poland.

For our study, the BDOT10k product was chosen because it provides the finest spatial details available as official geospatial information with a level of detail corresponding to contemporary, civilian topographic map scale of 1:10,000. The BDOT10k product is a spatially continuous vector database with a different thematic legend than the UA map product. The Topographic Objects Database contains information concerning networks of watercourses (SW), networks of roads and railways (SK), networks of utility lines (SU), land cover (PT), protected areas (TC), administrative units (AD), buildings, structures and equipment (BU), land development complexes (KU), and other objects (OI). On 31 July 2000 The BDOT10k data was made available publicly through web services at the following address: https://www.geoportal.gov.pl/en/dane/baza-danych-obiektow-topograficznych-bdot .

Note that the geometric accuracy of the geospatial entities are much better than those of the UA. Any BDOT10k singular topographic object, e.g. electric pole, building footprint, available in the database ranges between 1.5 m and 5 m, depending on the type of object and in accordance with the Regulation (Rozporzadzenie, 2011a). The posted land cover or land use class objects accuracy is equal to 10 m. Other geometric object conditions are specified as follows: the minimum distance between vertices is 2 m, and the accuracy of mapping angles is 1 degree, the precision of recording coordinates of points, polylines and polygons constituting geometric representation of objects is 0.01. Consequently, the BDOT10k information is much more accurate than the UA information.

In the following table (Table 2), the land cover classes that provide similar descriptions to those of the UA map product were extracted and presented. These will be used in the comparison and calculation of SDG 11.7 relevant statistics and used as the reference data set for the two cities.

Table 2 – A list of the BDOT10k classes similar in land cover class description and comparable to the UA map product.

Polish Database of Topographic Objects (BDOT10k) feature classes		
Class level	**Class code**	**Class description**
II	PTTR	Grassland or herbaceous vegetation (land cover data)
II	PTRK	Shrubby vegetation (land cover data)

II	PTLZ	forests and wooded area (land coverdata)
II	PTUT	Allotment gardens, fruit orchards, ornamental plant nurseries (land cover data)
III	KUSK04	Parks (land use data)
III	KUSK03	sports and leisure centre/facilities (land use data)
III	PTZB (01-02)	residential areas (land cover data)
II	PTZB	built-up areas (land cover data)
III	BUBD (01-06)	residential buildings (footprints topographic data)
II	BUBD	all buildings (footprints topographic data)
II	BUSP	sports facilities buildings (footprints topographic data)

2.2 METHODOLOGY

2.2.1 How to define green and public spaces?

As described in the introduction, our goal is to develop a methodology that can help anyone produce SDG 11.7 reporting statistics that can be compared quantitatively anywhere in the world. However, the first difficulty especially from a geospatial thematic perspective is how to define what is considered to be a safe, inclusive and accessible, green and public space as recommended and described in SDG 11.7. As all geospatial practitioners are very well aware, it is possible to define green and public spaces in a variety of ways depending on the author and the application. Moreover, most publications reviewed fail to define what is meant by the term greenspace. Of those that do provide a definition, six different definition types are identified. Consequently, Taylor and Hochuli (2017) recommend that a definition that is both qualitative and quantitative is required.

Around the world, urban green spaces can exist in a variety of types, structures, and shapes. These urban green spaces can also include public parks, reserves, sports fields, streams, river banks and other riparian areas, greenways, walkways and trails, communal shared gardens, street trees and bushes, nature conservation areas, and less conventional spaces such as green walls, green alleyways, and cemeteries (Roy et al., 2012).

According to the World Health Organisation (WHO), urban green space is defined in the following manner: *all urban land covered by vegetation of any kind. This very broad definition therefore covers vegetation on private and public grounds, irrespective of size and function, and can also include small water bodies such as ponds, lakes or streams* (WHO, 2017). A different definition of natural green spaces provided by Natural England (2010) is the following: *places where human control and activities are not intensive so that a feeling of naturalness is allowed to predominate*.

Note that the SDG 11.7 recommendation also refers to accessibility which is a further constraint when defining such green spaces. Vargas-Hernández et al. (2018) looks at this in a more pragmatic manner taking into account the uses of such green areas in urban settings and provides the following definitions: *Accessibility to urban green spaces is related to ease of* *access by proximity with no physical barriers, transportation, open gates at an early hour, accessibility for disabled people, information on cues and path-finding features, maps, information at the entrance, path junctions, slopes, and cambers, an attendants for those with disabilities and visual impairment. Improving safety issues requires changes in the use of fencing, lighting, staff or rangers, removal of cars, restriction of cycling, roller-skating, and roller-blading, etc. Urban green areas are safer gathering places for children and young people, at least safer than being on the street.*

The definition of Vargas-Hernández et al. (2018) continues to also provide a definition of inclusiveness and not only of the land-cover and land-use: *Access to urban green spaces for the elderly, the disabled, children, women, and minority ethnic groups concerns issues such as ease of entrance, proximity, social inclusion, provision for the visually impaired, public transport, parking, moving safely, and surface design. Awareness and understanding of social inclusion in urban green areas is a recognition of the particular social and cultural needs and aspirations of users who are most likely to be excluded in society*. Many times, such detail is not necessarily observed or can be quantitatively measured from space observations.

2.2.2 How to measure accessibility of green and public spaces?

The UK Design Council in 2010 wrote: "No one knows exactly how many green spaces there are in our urban areas, where they are, who owns them or what condition they are in" (UK Design Council, 2010). This statement was made as part of the Urban Green Nation: Building the Evidence Base where a review of indicators that capture some element of green space was undertaken. This further highlights the potential difficulties of not only defining green urban spaces but also how to measure them.

For this particular experiment, the chosen measure to describe accessibility and availability of Urban Green Spaces (UGS) was adapted from the Accessible Natural Greenspace Standard (ANGSt) proposed in 2010 (Natural England). This UGS definition is composed of two quantitative metrics: availability as a ratio of natural green spaces per capita, and accessibility as a derivative of the size of the area and their distance from residential areas. According to the ANGSt recommendations, each resident should have access to natural green areas of different sizes that can range from 2 to 500 ha, and located within a radius of 300 m to 10 km from their place of residence (Natural England, 2010). Furthermore, we define UGS accessibility at different levels of detail. At the macro-level, UGS accessibility is expressed as a percentage of the total settlement area, e.g. administrative border, where UGS are accessible. At the meso-level, we define accessibility expressed as a percentage of the total statistical circle area that has accessible UGSs. Whereas at the micro-level, we define UGS accessibility as a percentage of the total number of housing units within the green spaces service area (Šiljeg et al., 2020).

2.2.3 The Experimental Implementation

The following steps were applied in order to produce the experimental results that are presented in the next section.
Step 1 – Preparation of the reference data. Choosing the relevant BDOT10k database feature classes for this application;
Step 2 – Preparation of the UA data. Choosing the applicable UA classes based on the detailed UA classes definitions and the (visual) comparison of its geometric range with the reference data;
Step 3 – Spatial analysis of the UGS accessibility. Based on the Accessible Natural Greenspace Standard (ANGSt) indices methodology presented above, the following was applied to both the reference and UA input data:

- Condition I = UGS of at least 2 ha should be located no more than 300 m from home;
- Condition II = UGS of at least 20 ha should be located no more than 2 km from home;
- Condition III = UGS of at least 100 ha should be located no more than 5 km from home;
- Condition IV = UGS of at least 500 ha should be located no more than 10 km from home.

Step 4. A comparative analysis of the results.

3. RESULTS and DISCUSSION

Reference Data Preparation

To build a suitable UGS reference dataset, the following BDOT10k land cover classes were included in the study: grassland or herbaceous vegetation, shrubby vegetation, forests and wooded area and allotment gardens, fruit orchards, ornamental plant nurseries. For the identification of residential areas for reference, the BDOT10k residential areas land cover data was used. Note that a Variant B was also generated as reference data for residential classes which is made up of the residential buildings' footprints.

Preparation of Urban Atlas Data

The UA data consists of the class named 'green urban areas'. According to the technical specifications of the Copernicus Urban Atlas product (Mapping Guide, 2018), this land cover/ land use class covers public green areas for predominantly recreational use such as gardens, playgrounds, zoos, parks, castle parks and cemeteries, and also sub-urban natural areas managed as urban parks, and forests or green areas extending from the surroundings into urban areas. This definition is dependent on the fact that at least two sides are bordered by urban areas and structures, and traces of recreational use are visible. However, it is enough to perform quick visual comparison with the reference data to realise that the UA green urban areas class contains only a fraction of the UGS classes available through the reference data (see Figure 1).

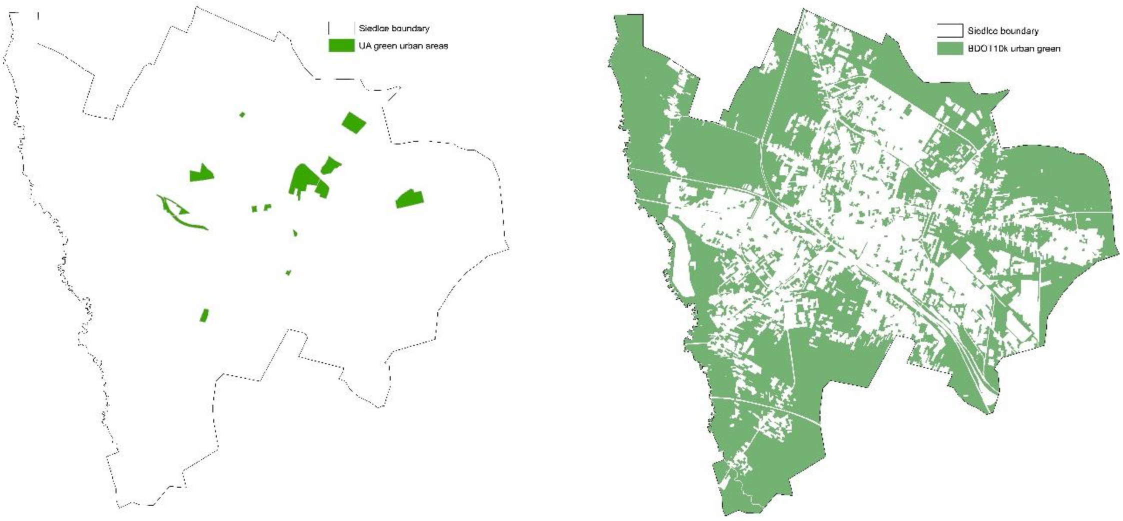

Figure 1 – Map of the Siedlce town. Left side presents the Urban Atlas green urban areas classes. The right side is the BDOT10k UGS classes merged as described in the text.

As shown in Figure 1, the side-by-side comparison with administrative reference data shows that simply integrating the UA green urban areas classes does not sufficiently compare to the reference UGS classes. Therefore, it was necessary to merge the following UA land cover classes that were also identified within the urban region and could be construed as UGS: UA green urban areas, UA sports and leisure facilities, UA forests and UA herbaceous vegetation, UA pastures and UA arable land. To create the non-UGS classes linked to residential areas, the urban fabric classes were used as data representing buildings. The linking of cover classes applied are shown in Table 3.

Table 3 – The list of Urban Atlas cover classes merged as Urban Green Spaces (UGS) for this experiment.

Urban Atlas Land Cover classes		
Class level	**Class code**	**Class name and description**
1.1.1	11100	Continuous urban fabric Areas where non-linear areas of vegetation and bare soil are exceptional
1.1.2.1	11210	Discontinuous dense urban fabric Possible some larger fraction of non-sealed and/or vegetated surfaces: gardens, parks, planted areas and non-surfaced public areas.
1.1.2.2	11220	Discontinuous medium density urban fabric The vegetated areas are larger, but the land is not dedicated to forestry or agriculture
1.1.2.3	11230	Discontinuous low density urban fabric The vegetated areas are predominant, but the land is not dedicated to forestry or agriculture
1.1.2.4	11240	Discontinuous very low density urban fabric

		The vegetated areas are predominant, but the land is not dedicated to forestry or agriculture
1.4.1	14100	Green urban areas Public green areas for predominantly recreational use such as gardens, playgrounds, zoos, parks, castle parks and cemeteries. Suburban natural areas that have become and are managed as urban parks. Forests or green areas extending from the surroundings into urban areas are mapped as green urban areas when at least two sides are bordered by urban areas and structures, and traces of recreational use are visible
1.4.2	14200	Sports and leisure facilities All sports and leisure facilities including associated land, es. associated green areas, parking places, etc. whether public or commercially managed
3.1	31000	Forests (except these in class 1.4.1)
3.2	32000	Herbaceous vegetation associations Vegetation cover more than 50%, ground coverage of trees with height >5 m: <30%, areas with minor/without artificial or agricultural influence
2.3	23000	Pastures Pasture and meadows, wooded meadows, pastures with scattered trees.
2.1	21000	Arable land (annual crops)

The UGS classes needed to be merged especially for the UA based urban maps. In order to identify the residential areas within the cities under investigation, the Urban Fabric class was used from the UA map to represent residential areas. For the reference dataset, the BDOT10k residential areas class was used to define the locations where people live.

Spatial Analysis of Urban Green Spaces Accessibility

The steps described in the previous section were applied to the two urban areas of interest, Siedlce and Warsaw. The next set of figures presents the results of these computations with respect to analysing UGS accessibility from both EO and administrative reference sources. The figures 2 to 4 present the results for Warsaw and figure 5 to 7 the results for Siedlce.

The figure 2 and 3 presents the differences that can be observed from the land cover classes associated with the needs of reporting SDG 11.7. Note that one of the most obvious visual issues is the accuracy of the land cover classification between the UA and reference datasets.

The results of the calculation of the ANGSt index for Condition I are shown in figure 4 for the city of Warsaw. The Warsaw UGS accessibility was computed as

$$124.27 \text{ km}^2 / 154.62 \text{ km}^2 = 80.4\%$$

based on the Urban Atlas combined classes datasets. The same was computed for the reference data set (BDOT10k) with the following result:

$$105.17 \text{ km}^2 / 112.27 \text{ km}^2 = 93.7\%$$

This result shows that there is a difference of greater than 10% in the result of the ANGSt index Condition I depending on the input data. The reference result based on BDOT10k data is better than that based on UA inputs. Note that the results presented are based on Condition I which requires at least 2 ha of UGS to be located no more than 300 m from home.

Figure 2 – Presentation of the regions where residential areas are found in the city of Warsaw. Left side: The urban fabric class from the Copernicus Urban Atlas map product. Right side: the reference BDOT10k residential areas class.

Figure 3 – Presentation of the regions where Urban Green Spaces are located in the city of Warsaw. Left side: the combined classes that represent green spaces from the Copernicus Urban Atlas map product. Right side: the reference BDOT10k combined urban green areas.

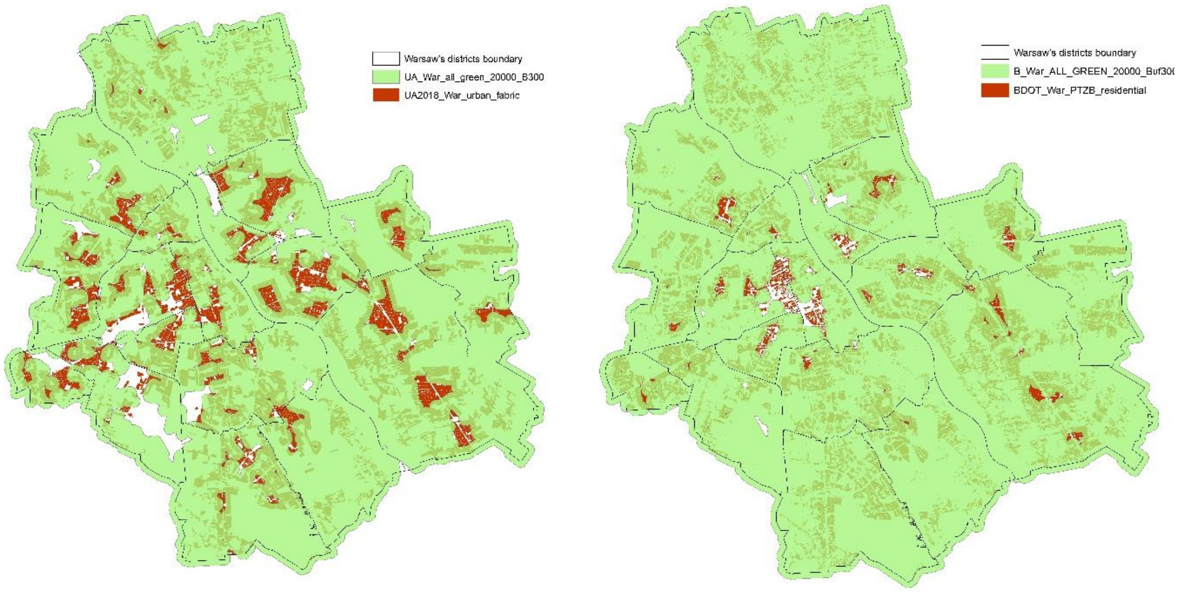

Figure 4 – The results of the calculation of the of the ANGSt index for Condition I for the city of Warsaw. Left side: result based on Urban Atlas based inputs. Right side: result based on reference BDOT10k data.

The second experiment involved the town of Siedlce where the next figures present the same types of information as those presented above for Warsaw. In figure 5, the areas where people reside are presented and in figure 6, the UGS is presented.

Figure 5 - Presentation of the regions where residential areas are found in the town of Siedlce. Left side: The urban fabric class from the Copernicus Urban Atlas map product. Right side: the reference BDOT10k residential areas class.

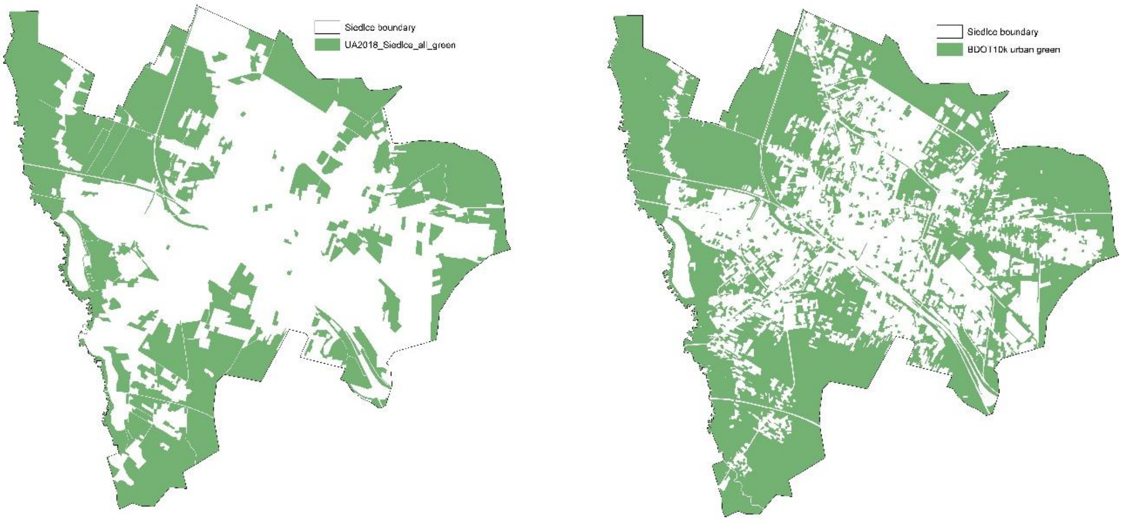

Figure 6 - Presentation of the regions where Urban Green Spaces are located in the town of Siedlce. Left side: the combined classes that represent green spaces from the Copernicus Urban Atlas map product. Right side: the reference BDOT10k combined urban green areas.

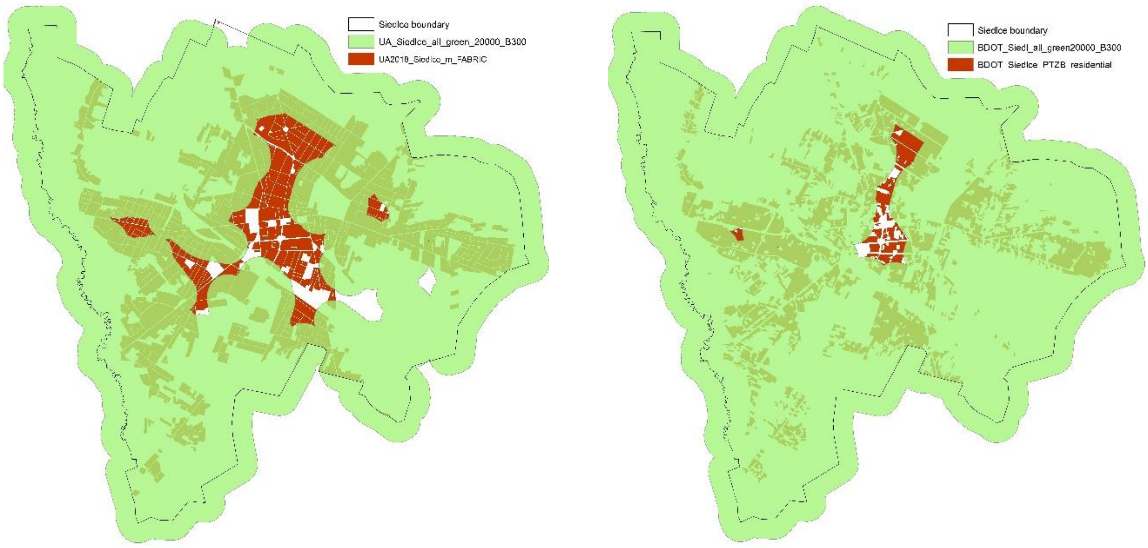

Figure 7 - The results of the calculation of the of the ANGSt index for Condition I for the town of Siedlce. Left side: result based on Urban Atlas based inputs. Right side: result based on reference BDOT10k data.

The results of the calculation of the ANGSt index for Condition I are shown in figure 7 for the town of Siedlce. The Siedlce UGS accessibility was computed as

$$8.76\ km^2 / 10.93\ km^2 = 80.1\%$$

based on the Urban Atlas combined classes datasets. The same was computed for the reference data set (BDOT10k) with the following result:

$$6.24\ km^2 / 6.73\ km^2 = 92.7\%$$

This result shows that there is a difference of greater than 10% in the result of the ANGSt index Condition I depending on the input data. The reference result based on BDOT10k data is better than that based on UA inputs. Note that the results presented are based on Condition I which requires at least 2 ha of UGS to be located no more than 300 m from home.

Discussion of the Results

It is interesting to note that the two UGS results based on the Condition I for the largest city in Poland and for a town whose population is 90% smaller are similar, i.e. on the order of 80% based on UA and 90% based on BDOT10k reference data respectively. This is an interesting result in itself but will be researched in more depth in another experiment.

However, the more significant result is the fact that there is at least 10% difference between the UGS Condition I result when using the UA inputs as opposed to the reference BDOT10k classification. This can be linked at this time to a number of different issues including the spatial accuracy of the UA data compared to the reference as well as the differences in the class definitions between these two datasets. For example, the MMU of the UA maps is 0.25 ha which is significantly less accurate than the reference data. By altogether missing such class sizes across a large urban area could significantly affect the UGS calculations. However, because this experiment concentrated on the Condition I where at least 2 ha should be located no more than 300 m from home, a finer MMU is better. This may not affect the other Conditions because they are based on larger areas and distances.

For the calculation of relevant SDG 11.7 indicators, the use of the UGS provides information about access to urban greenery because the higher the calculated percentage, the better the availability of UGS to citizens. Based on the presented results, the two places in Poland achieve quite high results: >90% based on the reference data whereas the UA based results are closer to 80%. It could be interesting to compute the UGS measures on smaller regions within the urban area and see whether more local details can be extracted from the technique. While such patterns were not identified visually in the present context, other cities around the globe may exhibit this pattern.

Another important aspect that should be mentioned about the Poland context is the fact that none of the cities have very high residential buildings. The population density and the access to the UGS should be taken into account when developing such indicators. Furthermore, from an EO perspective, cities with many high buildings also cover the green spaces which may be found on the ground but overshadowed biasing the classification of UGS.

Note that neither of the UGS calculations take into account the physical accessibility to the UGS, i.e. type of road and/or transport or the physical state of paths inside of the areas. Such geospatial information must be acquired from other sources than satellite based EO.

4. CONCLUSIONS

The goal of our experiment was to produce an initial understanding of the potential differences between EO based map products for use in the calculation of the SDG 11.7 indicators. Access to such open spatial data would help develop sustainable decisions for cities all around the world. The main conclusion stemming from this work demonstrates that Copernicus Sentinel-2 based map products for urban areas can provide the necessary land cover class information to compute indices related to access to Urban Green Spaces. However, there is a quantifiable negative discrepancy between the EO based result and the reference from public administration. An underestimation of 10% was observed in the case of Poland but was still showed good accessibility to UGS. Such a difference could be more important if the percentage to UGS accessibility is lower. More research and testing into the reason for this consistent bias is needed. Furthermore, it was necessary to combine a number of Urban Atlas thematic classes in order to attain a similar pattern of UGS as that presented by the reference data. This need to combine classes should be investigated further in the future.

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BIOGRAPHICAL NOTES

Dr Eng. Joanna Nowak Da Costa is research and teaching associate at Military University of Technology. Her current research interests are geographically referenced data quality, regularities in the spatial distribution of complex geographically referenced phenomena, and the effects of the flattening of the Earth and cartographic projections on distances, angles, and areas of polygons on maps.

Dr. Conrad Bielski is a geospatial expert who has been working in the remote sensing field for over 25 years. His main interests are in applying automated image processing to solve customer pain points and help provide sustainable solutions to a variety of stakeholders based on open data and open standards.

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